

NATURAL OCCURRENCE OF MgSiO_3 -ILMENITE AND AMORPHIZED $(\text{Mg,Fe})\text{SiO}_3$ -PEROVSKITE IN A SHOCKED L5-6 CHONDRITE T.G. Sharp^{1,2}, C.M. Lingemann^{3,4}, C. Dupas², D. Stöffler⁴. ¹Department of Geology, Arizona State University, Tempe, AZ 85287, USA, ²Bayerisches Geoinstitut, Universität Bayreuth, D-95440 Bayreuth, Germany, ³Institut für Planetologie, Westfälische Wilhelms-Universität Münster, D-48149 Münster, Germany, ⁴Museum für Naturkunde, Institut für Mineralogie, Humboldt-Universität zu Berlin, D-10115 Berlin, Germany.

Introduction

The most common natural occurrences of mafic high pressure minerals are in melt veins of chondrites that result from shock metamorphism during impact events on the chondritic parent bodies. The mineral assemblages in these melt veins provide important information concerning the pressure and temperature conditions of melt-vein crystallization when combined with information from dynamic and static high pressure experiments [1-8]. The sample examined in this study is an L5-6 (S6) chondrite known as ACFER 040, which was found in 1989 in the Algerian Sahara [9]. The sample is a breccia that contains a large number of black melt veins and pockets [3-5]. The melt-vein matrix of this sample was examined by ATEM to better understand the conditions of melt vein crystallization.

Results

The melt vein matrix consists of a mixture of equant grains of amorphous material of approximately 2 μm ($1.9 \pm .4 \mu\text{m}$) in size, surrounded by finer mineral grains and interstitial glass (Fig. 1A). Electron diffraction patterns collected from the equidimensional grains confirm that they are amorphous (Fig. 1A), although in some cases they contain tiny inclusions (40 to 250 nm) of crystalline material. EDS analyses of the amorphous grains show that they have a composition very similar to that of the majorites that commonly occur in the matrix of shock-melt veins [10,2,5,6]. The compositions of the amorphous grains are quite distinct from that of the interstitial glass that occurs between the surrounding crystals (Fig. 1B). The interstitial glass contains a substantial amount of P_2O_5 as well as more CaO and less FeO than the amorphous grains.

The principal phase comprising the crystalline material between the amorphous grains (Fig. 1A and B) has a composition similar to enstatite with a small amount of Al_2O_3 , Na_2O and Cr_2O_3 . Electron diffraction patterns from these crystals can only be indexed as the ilmenite structure of MgSiO_3 , a high-pressure polymorph of enstatite (Fig. 1B). The MgSiO_3 -ilmenite grains have variable morphologies, with most forming prismatic crystals up to several microns long. Many grains contain tiny planar defects that are visible as small spots or platelets with local strain contrast (Fig. 1B).

The second crystalline phase in the melt vein matrix is ringwoodite (Fig. 1B), the spinel structure polymorph of $(\text{Mg,Fe})_2\text{SiO}_4$ olivine. Ringwoodite grains can be either equidimensional or somewhat elongated, ranging in size from about 400 nm to about 1 μm . They have very high densities of stacking faults on {110} planes, with the faults commonly occurring as short (100 to 200

nm) segments. The textural relations between ringwoodite and MgSiO_3 -ilmenite indicate that these two minerals crystallized simultaneously.

Discussion

The amorphous grains in the matrix cannot be easily explained as a quenched remnant of melt because of the non-random distribution of the surrounding crystals. The distinct difference in composition between the amorphous grains and the interstitial glass is also inconsistent with the amorphous grains being remnants of quenched melt. A possible explanation is that the amorphous grains represent material that was crystalline at high-pressure and became amorphous after pressure release. Majorite is not a likely precursor to the amorphous material because it does not readily amorphize during sample preparation or electron irradiation during TEM. $(\text{MgFe})\text{SiO}_3$ -perovskite, which has a composition similar to that of majorite, is a likely precursor to the amorphous grains because it is extremely unstable at low pressure. It is known to become amorphous at one atmosphere if heated to a temperature greater than 150 °C [11] or when crushed in a mortar and pestle at room temperature [12]. We conclude that the amorphous grains represent a chemically complex silicate perovskite that crystallized from the melt at high pressure. The same interpretation of MgSiO_3 -rich glass plus magnesiowüstite was made by Mori [1]. The post-shock waste heat that is produced during decompression of shocked materials can produce temperatures as high as 1750 °C [13], far in excess of the temperatures required to cause $(\text{MgFe})\text{SiO}_3$ -perovskite to become amorphous.

Crystallization of the melt vein appears to have involved three silicate phases as well as Fe-Ni metal and troilite. The distribution of minerals and glass grains suggests a sequence of crystallization that started with nucleation and growth of perovskite followed by the simultaneous nucleation and growth of MgSiO_3 -ilmenite and ringwoodite at high pressure and temperature followed by the crystallization of the metal-sulfide melt at 980 °C. The assemblage consisting of $(\text{MgFe})\text{SiO}_3$ -perovskite, MgSiO_3 -ilmenite, and ringwoodite is not predicted by the liquidus phase diagram [14] for the Allende carbonaceous chondrite. This may reflect the difference in composition between the Allende carbonaceous chondrite and the ACFER 040 ordinary chondrite or the rather strong effect of P_2O_5 on the liquidus phase relations in mafic systems [15]. Another possible explanation is that the assemblage simply cannot be approximated by an equilibrium phase diagram if the crystallization occurred while the pressure

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and temperature were rapidly decreasing during the release phase of shock metamorphism.

We report here a new assemblage of $(\text{MgFe})\text{SiO}_3$ -perovskite (glass), MgSiO_3 -ilmenite, and ringwoodite in the melt veins of the ACFER 040 L5-6 chondrite. As far as we know, this is the first natural occurrence of MgSiO_3 -ilmenite reported. Although perovskite is no longer crystalline, it appears to have been the first mineral to crystallize from the melt and therefore represents a higher crystallization pressure than the more common majorite-bearing assemblages in the melt veins of other shocked chondrites.

References

- [1] Mori, H. (1994) *J. Mineral. Soc. Japan* 23, 171-178. [2] Langenhorst, F. et al. (1995) *Geochim. Cosmochim. Acta* 59, 1835-1845. [3] Lingemann, C.M. and Stöffler, D. (1994) *Meteoritics* 29, 491-492. [4] Lingemann, C.M. and Stöffler, D. (1995) *LPSC XXVI*, 851-852. [5] Lingemann, C.M. et al. (1995) *Meteoritics* 30, 537. [6] Chen, M. et al. (1996) *Science* 271, 1570-1573. [7] Chen, M. et al. (1996) *LPSC XXVII*, 211-212. [8] Sharp T.G. et al. (1996) *LPSC XXVII*, 1175-1176. [9] Bischoff, A. and Geiger, T. (1995) *Meteoritics* 30, 113-122. [10] Smith, J.V. and Mason, B. (1970) *Science* 168, 832-833. [11] Wang, Y. et al. (1992) *JGR* 97, 9 12327-12347 [12] McCammon, C.A. et al. (1992) *Am. Mineral.* 77, 894-897. [13] Stöffler, D. and Langenhorst, F. (1994) *Meteoritics* 29, 155-181. [14] Agee, C.B. et al. (1995) *JGR* 100 B9, 17725-17740. [15] Toplis, M.J. et al. (1994) *Geochim. Cosmochim. Acta* 58, 797-810.

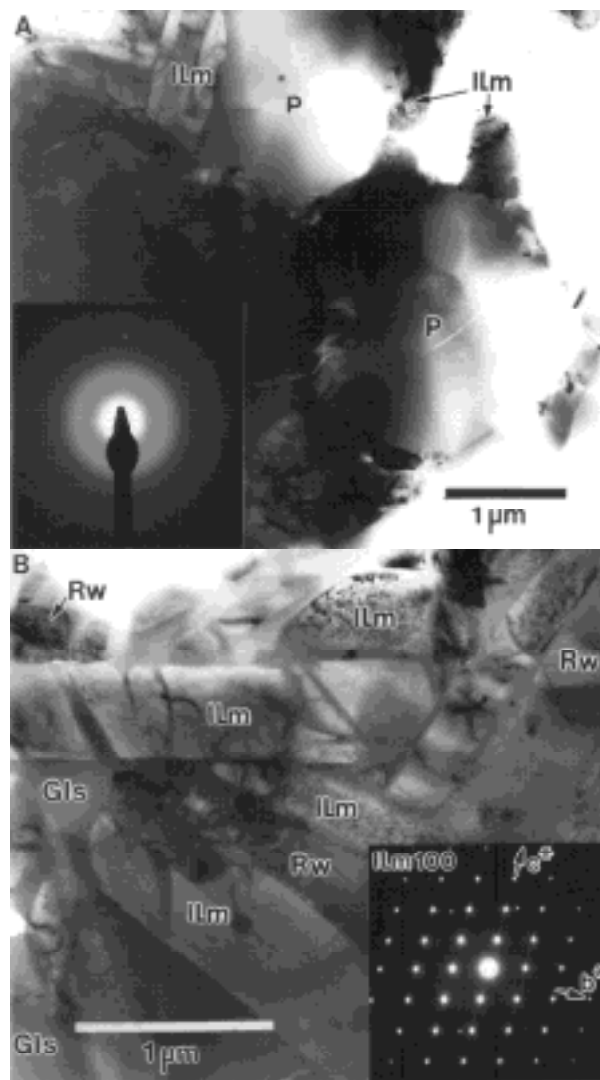


Fig. 1 Bright-field TEM images of the melt vein matrix in ACFER 040. (A) Amorphous grains (P) surrounded by crystals of MgSiO_3 -ilmenite (ILm) and ringwoodite are common. Electron diffraction from the pockets (A) demonstrates that they are amorphous. (B) Between the pockets, the matrix consists of prismatic grains of MgSiO_3 -ilmenite (ILm) as well as ringwoodite (Rw) and interstitial glass (Gls). The [100] zone axis diffraction pattern of MgSiO_3 -ilmenite is also shown. Many of the MgSiO_3 -ilmenite grains (B) have lattice defects that appear as dark spots in images and produce streaking along c^* in diffraction patterns.